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Research on acoustic source positioning method for boilers tube leakage

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ABSTRACT

By examining the shortcomings of the current condition monitoring system for boiler pipeline leakage, a new method is presented in this paper to accurately identify the leakage location using multi-microphones array for passive source localization. A model of 660MW boiler is taken as an example for simulating the localization of various positions of the leakage source in the furnace of the boiler's body. This paper also discusses the effect of sound propagation through the combustion temperature-field inside the boiler and the reverberation in the boiler enclosure on the leakage localization, and subsequent amendment in the localization techniques. It is shown that the combustion temperature gradient field clearly influences localization of the leakage.

INTRODUCTION

Boiler tube burst is a frequently occured accident in thermal power plants, which has tremendous impact on the safety and cost of the plants. In the Boiler Pipeline Leak Detection System, multiple microphones are installed in the boiler to monitor the acoustic signals of leakage in real-time. If a leakage can be detected before it develops into devastating burst, a proper shutdown can be arrangemented for effective maintenance, which is of a great significance to plants.

At the present, the Boiler Tube Monitor Systems (BTMS) have already been put in use in plants. However, the localization of the leak point is not accurate and there are occasional mistakes in localization because of the imperfect technology in use. This paper examines the acoustic detection and leakage localization technology and its influencing factors, such as the combustion-temperature field and the reverberation. The outcome from this study may lead to a further development of the technology for more accurate leakage localization.

RESEARCHES ON ACOUSTIC DETECTION METHOD

In a boiler, the background noise is a low-frequency sound signal dominated by the combustion noise, while the leakage sound is a high-frequency signal of broad band shaped by the acoustic characteristics of the boiler. The microphones installed on the furnace detect the occurances of the leakage by checking if there is any high-frequency leakage signal.

It is necessary to do some noise reduction process to the received signal because of the leakage sound and background noise superimposed together. The noise reduction method was Band-pass filter, which would combine with spectral analysis for development. Moreover, the wavelet transform has emerged as a better denoising method with the development of modern signal processing techniques. Simulation work has been done to demonstrate the suppression of the background noise in the boiler. Some results are presented as follows.

Firstly, an original signal generated by the computer on behalf of leak acoustic signal, which is shown in Fig. 1(a); secondly, take an operation noise measured in a certain boiler as background noise, which is shown in Fig. 1(b); and then superimposed the two signal with each other, which is shown in Fig. 1(c); finally, the wavelet transform is used to de-noising which is shown in Fig. 1(d). From the last figure it is noted that the background noise is significantly reduced. These results indicate that this siganl detection technology can be used to reduce the probability of false and omission of positives effectively.

In BTMS, the localization process is mainly based on the magnitude of bursting sound and decay of the magnitude with the distance between the leakage source and measurement location. However the location of the leakage is a region not a point, which is the rising concern of researchers. In this paper, the acoustic design software EASE is used to observe the distribution of leakage sound intensity in a 660MW boiler model. We assume the leak point S occurs at the central lateral position in furnace, while the receiving points A and B are assumed on the side and opposite furnace of the leak point S. When the leak has its directivity, the 3dB coverage region (the sound magnitude is reduced to 50%) is shown in Fig. 2. The magnitude at point B is stronger than that at point A but it is further away from the leak point S. Therefore we conclude that using sound magnitude to determine the leak point may not be accurate for some situations. The passive acoustic localization method, which is based on time-delay estimation, should be considered as a more accurate option.

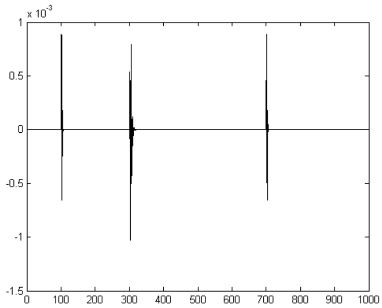

Fig.1(a) The original signal

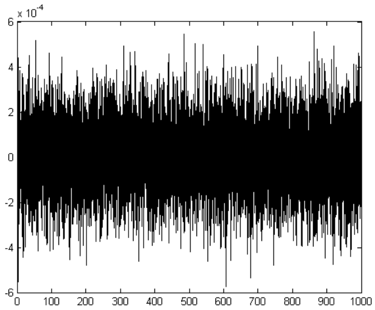

Fig.1(b) The background noise

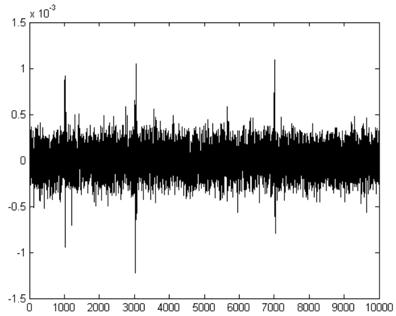

Fig.1(c) Superposition of the two signals

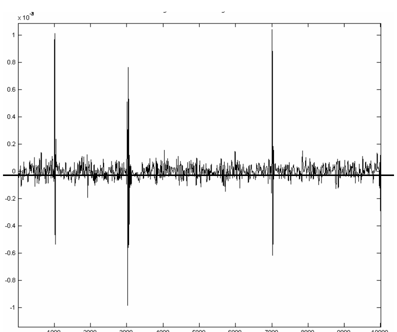

Fig.1(d) The denoising results of using wavelet transform

RESEARCHES ON PASSIVE SOUND SOURCE LOCALIZATION METHODS

The 3D model of the boiler with an leakage at point S is shown in Figure 2 by using EASE software. And the micro-phones installed in the furnace can be used as a multi-microphone array to locate the position of the leakage by using the relative time-delay. The process is explained in the following two sections.

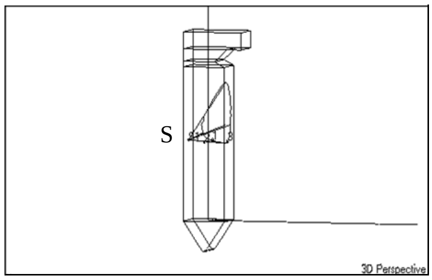

Fig.2 The boiler model with an leakage at point S

1、The time-delay estimation

The time-delay collected by each microphone is estimated by the generalized cross-correlation method, for its advantage of noise suppression. The formula for calculating the correlation function R_{12} is:

$$R_{12}(\tau) = F^{-1}[\psi_{12} F(x_1)^* F(x_2)] \qquad (1)$$

where F and F^{-1} represent direct and inverse Fourier Transform, $*$ is a complex conjugate symbol, ψ_{12} is a weighting function in frequency domain and its role is to strengthen the spectral components of the received signal, thereby enhancing the accuracy of time-delay value.

In this paper, a MATLAB simulation of the generalized cross-correlation method has been undertaken by using the sweep signal as the source signal, because it is similar to the real leak signal by some extent for its broad frequency range. The expressions of the two receive signals are x1=s1+0.5*randn(size(length(s1))) and x2=0.8*s2+1*0.5*randn(size(length(s2))), while there is 0.05 time-delay between them. And the simulation results are shown in Fig.3.

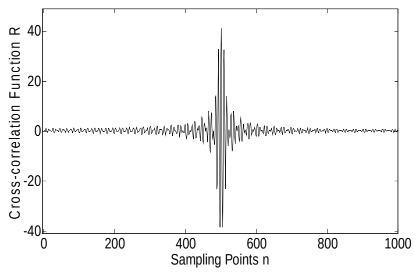

Fig.3 The signals and their correlation function

From the result we can get the time-delay of the two signals is 0.05s, which is consistent with the initial setting. Moreover, based on the theory and simulations, a time-delay experiment is conducted in a 660MW boiler, and the layout of the micro-phones points are shown in Fig.4.

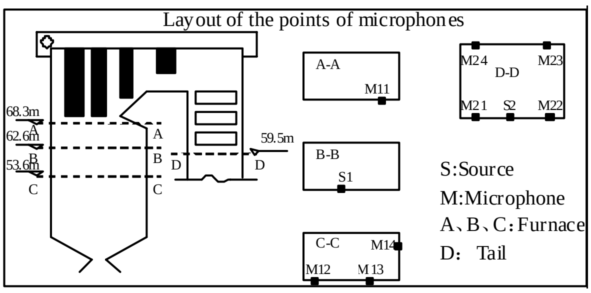

Fig.4 Layout of the points of microphones installed in boiler

Fig.5 The microphone installed on the furnace and other experimental facilities

The experimental facilities included a signal acquisition system (MKⅡ with 8-channels), and an acoustic analysis software PAK. The source is generated by SpectralLAB in a computer, and the results in this experimental are shown as follows.

Table1 The experimental results obtained in furnace

Number	Source	Δ_{12} (s)	Δ_{13} (s)	Δ_{14} (s)
1	Theoretical value	0.0248	0.036	0.0134
2	White noise	0.0247	0.0357	0.0117
3	Sweep signal (500-4000Hz)	0.0242	0.0357	0.0082
4	Sweep signal (1000-4000Hz)	0.0228	0.0322	0.0142
5	Sweep signal (2000-4000Hz)	0.0267	0.0324	0.0136

Table2 The experimental results obtained in tails

Number	Source	Δ_{12} (s)	Δ_{13} (s)	Δ_{14} (s)
1	Theoretical value	0.0447	0.0447	0
2	White noise	0.0464	0.0442	0.007
3	Sweep signal	0.0473	0.0420	0.003

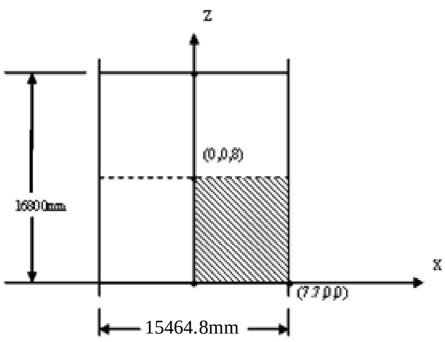

Fig.7 The left view of the simulation region

	(500-8000Hz)			
4	Sweep signal (1000-4000Hz)	0.0438	0.0388	0.009

It is shown from the experiment data that the time-delay can be estimated accurately by the generalized cross-correlation method, and the error is merely 10^{-4} s.

2、The position calculation

The cross-shaped array with four elements is used in a boiler for the reason that it can fit the actual geometry structure of the boiler and the practical feasibility considerations, which is shown in Fig.6.

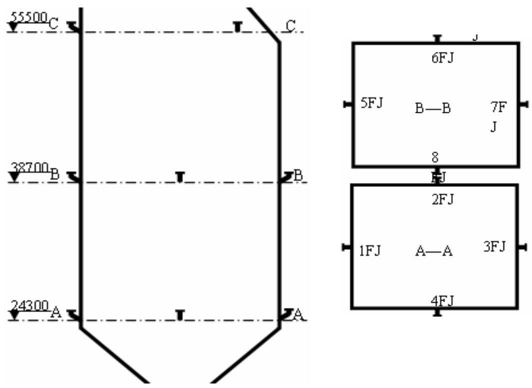

Fig.6 The geometry structure of a boiler and the layout of microphones

The passive acoustic positioning technology is based on the principle of sound ranging. We assume the microphone which first receives the leak signals is at the origin of the coordinate. Then the distances between the source point at $P=(x,y,z)$ and the receivers at $S_i=(x_i,y_i,z_i)$ for $i=1,2,3$ are described by:

$$xx_i+yy_i+zz_i-\sqrt{x^2+y^2+z^2}\,\tau_i c=\frac{r_i^2-(\tau_i c)^2}{2}\,(i=1,2,3) \tag{2}$$

The equations were solved by Newton iteration method. In the localization simulation in 660MW boiler model, the structure of the boiler and array are symmetrical, such that the leakage occurred in the shaded region in Fig.7 as an example, and the receiver arrays are marked as Array1 (the upper one) and Array2 (the lower one), which are shown in Fig.8.

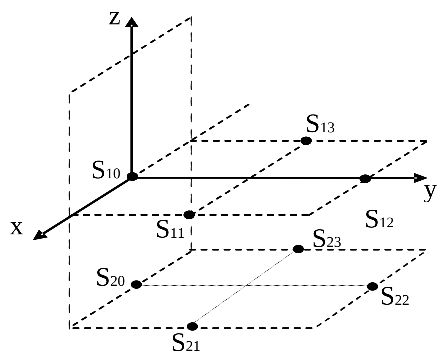

Fig.8 The layout of the receiver arrays

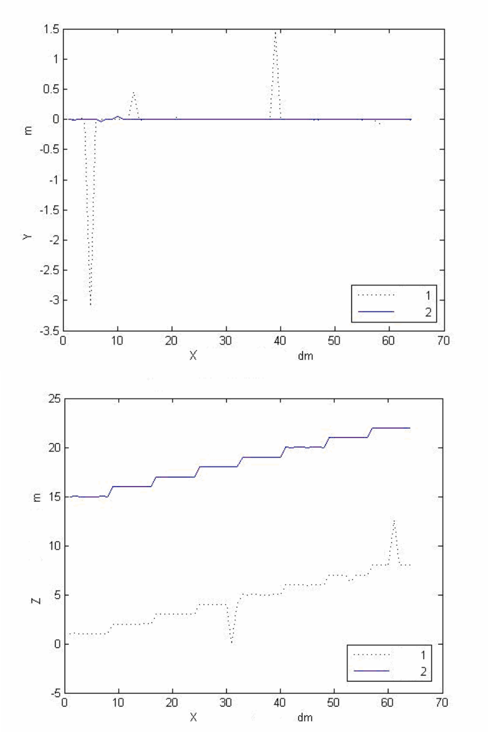

Fig.9 The comparation results between receiver Array1 and Array2

In Fig.9, the solid and dashed lines represent the results received by Array1 and Array2 of Y and Z direction,and from which we can see that both of the two receiver arrays can get the right position of the leak points, while the results obtained by Array2 are more accurate, with the error merely numbers of centimeters and without any exceptional point. As a result, the passive acoustic position method can be regarded as an effective method which is applied to the boiler tube leakage location technology.

THE ANALYSIS OF MAIN INFLUENCE FACTORS

We now analyse the effect of combustion temperature field and reverberation in the on the leakage positioning process.

1、Effect of combustion temperature field

The researches on the combustion temperature field is based on a model of the temperature field inside a boiler (see Figure 10), where the main property is the single-peak temperature of about 1800℃ in the center region. The temperatures at the edges are about 800-1000℃.

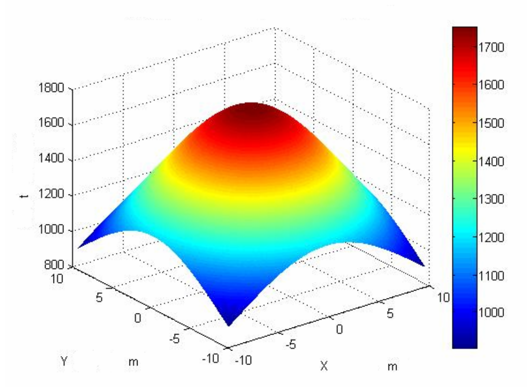

Fig.10 The temperature field model in a boiler

In the distribution of two-dimensional temperature expression of the distribution function $T(x,y)$ is shown as follows:

$$y'' = \frac{1+y'^2}{2T(x,y)}\left(y'\frac{\partial T(x,y)}{\partial x} - \frac{\partial T(x,y)}{\partial y}\right) \qquad (3)$$

which can be caclulated by numerical method. From the results, it is known that the sound path will be deviated by temperature.

Table3 shows the actual position of the source and calculated position by using the sound propagation path without considering the effect of temperature distribution.

Table3 The data of the positions deviation caused by a temperature field

Physical position	(-9.65,0)	(-9.65,-1)	(-9.65,-2)	(-9.65,-3)
Calculate results	(-7.0974,0)	(-7.0831,-0.9824)	(-7.0445,-1.9580)	(-6.7621,-3.0612)
Physical position	(-9.65,-4)	(-9.65,-5)	(-9.65,-6)	(-9.65,-7)
Caculate results	(-6.8956,-3.8295)	(-6.5697,-4.8106)	(-6.6675,-5.5564)	(-6.5297,-6.3451)

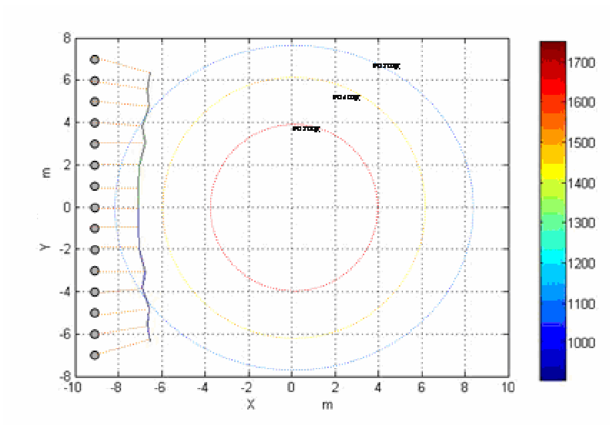

Fig.11 The deviation of the position results caused by a temperature field

In Fig.11, the small circles are the physical positions of leakage and the curve next to them are the calculate results, and the deviation results caused by a temperature field is that the position of the leakage points will move towards the center of the boiler about 2.5m.

2、Effect of reverberation

As the furnace of the boiler is enclosed, the leakage sound will be reflected by the walls and pipes in the signal propagation, so the receive signals is actually a reverberation signals, with the experssion of reverberation time of

$$T_{60} = 55.2\frac{V}{-c_0 S \log_e(1-\overline{\alpha})} \tag{4}$$

Taken the 660MW boiler as an example, the theoretical reverberation time is 3.0967s for the leakage sound signal at frequency of 2000Hz. In this paper, the reverberation has been simulated in the EASE boiler model (see Figure 12), and the result is 2.85s, which is not very difference from the theoretical value.

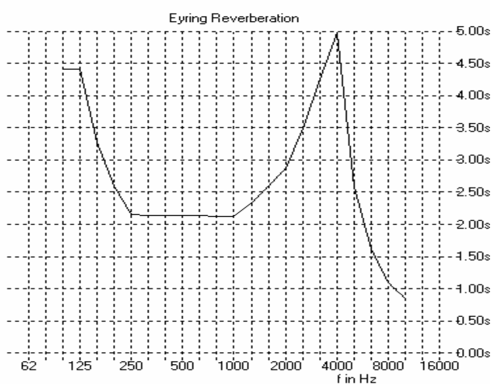

Fig.12 The simulation result of the reverberation in the EASE boiler model

However, the high-frequency leakage sound would be scattered seriously when its disseminated through a lot of dust filled inside the boiler. Therefore, it is necessary to amend the reverberation time on the following four aspects: the acoustic absorption coefficient for 2000Hz is amented to 0.035-0.045 as a treatment of the ashes on the furnace wall; the acoustic absorption coefficient of the upper and nether is 1 as a treatment of an open space because of the superheater pipelines and the wedge-shaped device in the boiler; the acoustic attenuation coefficient is 1.6202 on average because of the coal dust; and the velocity of the leakage sound incresed to 1171.6 m/s because of the combustion temperature. So the reverberation is amended to as follows:

$$T_{60} = 55.2\frac{V}{-Sc_0 \log_e(1-\overline{\alpha}) + 8\alpha V c_0} \tag{5}$$

The amended reverbertion result is (0.5595-0.5398)s, which may lead to a serious effect on the positioning of the leakage, so it is necessary to deal with it. Because of the reverberation signal is a reflected variant form of the leakage signal, its mathematical model can be expressed as a convolution signal. In this paper, the cepstrum method is used as the solution to eliminate the reverberation, which is a process of deconvolution in essence shown as follows:

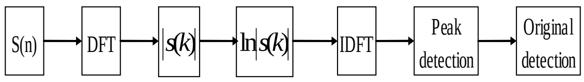

Fig.13 The principles of the cepstrum method

In this paper, the MATLAB program of the cepstrum method has been used to process the background noise signal collected in a boiler, and the result is 150Hz which is coincides well with the actual value. So the cepstrum method is an effective solution to eliminate the signal's reverberation, and can be used to reduce the error of the leakage location.

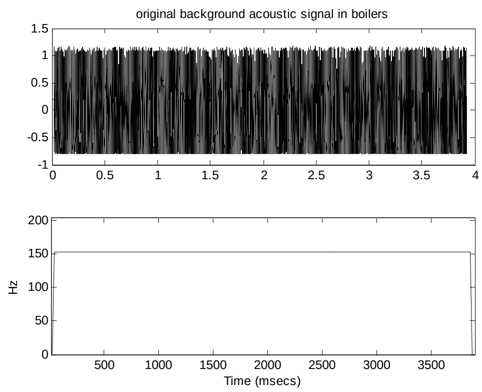

Fig.14 The background noise in a boiler and the cepstrum result of it

CONCLUSIONS

In this paper, the method of acoustic detection and localization for boiler tube leakage is analysed. In summary:

(1) The wavelet transform is an effective method to remove the effect of the background noise in boilers. Amplitude localization method in the current monitoring technology may cause false positives, as a result it must be improved by using method such as the array positioning technology.

(2) Using multi-microphones passive acoustic source localization method, the accuracy of the leak source localization can be improved effectively. The simulations based on this method also provide the accuracy range.

(3) The combustion temperature in the boiler will introduce error in calculated leakage position from its original position to towards the center of the boiler.

(4) The reverbertion is another factor which may cause error of the position results. In this paper, the cepstrum method is used as a solution to reduce the reverbertion effects of the leak source location.

The study may provide some useful infromation to the development of the leakage detection technology. However, there are still other inflence factors that may affect leak sound propagation in the boiler. Examples are sound scattering by the tubes and the sound catheter, which will be the topics of further research.

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